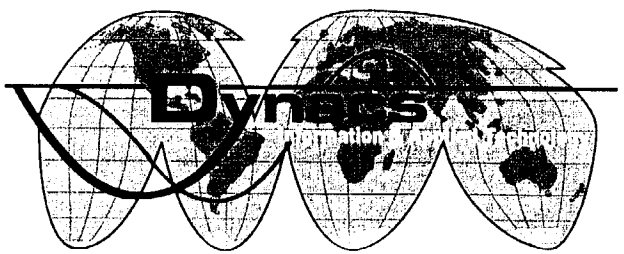
Multi Sensor Array

Dr. Christopher Immer

Dynacs, Inc.

Kennedy Space Center



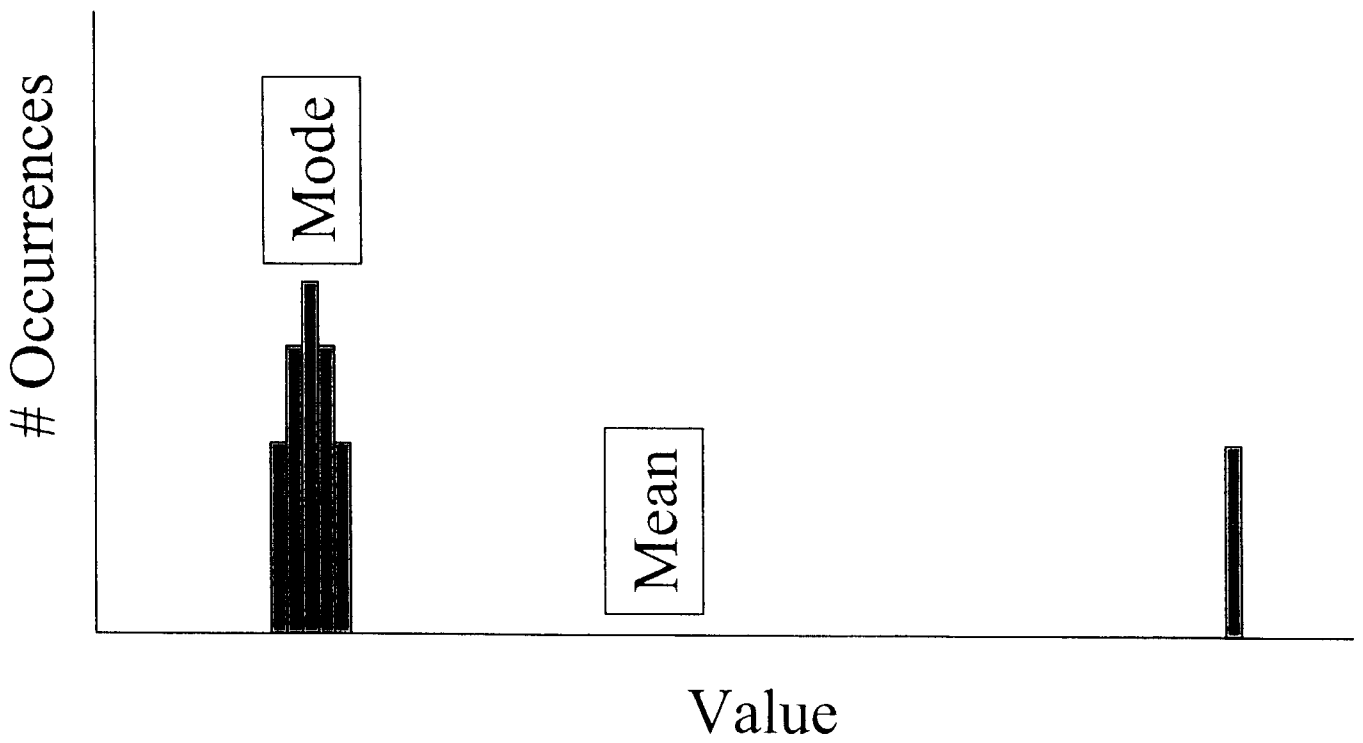
The Motivating Problem.

- As of May 1987 there were 2519 pressure transducers installed at the Space Shuttle Pads
- Each pressure transducer requires a calibration on average every 17 months.
- Calibration requires many man hours
- Many times when a sensor is pulled to be calibrated, its calibration is within spec and no action need be taken
- What is to ensure that calibration doesn't shift before it's cycle expires? How can you ensure that sensor is in calibration?
- To calibrate, a transducer is compared with another "standard" transducer

MSA Algorithm

- Put many sensors in where one would normally be
- Compare each element with every other
- Mathematically calculate weights for each element to determine which are "good" and which are "bad"
- Need to do more than mean, standard deviation
- Need something like a mode, or most common value, that works for continuous functions

Mean Vs. Mode



For what type of sensors will the MSA work?

- Elements in the cluster MUST be exposed to the exact same phenomenon
- For this reason, MEMS is attractive due to small size, close proximity: less likelihood for phenomenon gradients
- Sensors must all fail in different ways, algorithm cannot determine failure if all sensor drift exactly the same
- No Systematic (common) error
- We would rather have all out sensor failure instead of drift: worst case is when a sensor drifts. How do you know if it's sensor drift or phenomenon drift?

How Do you Test the MSA?

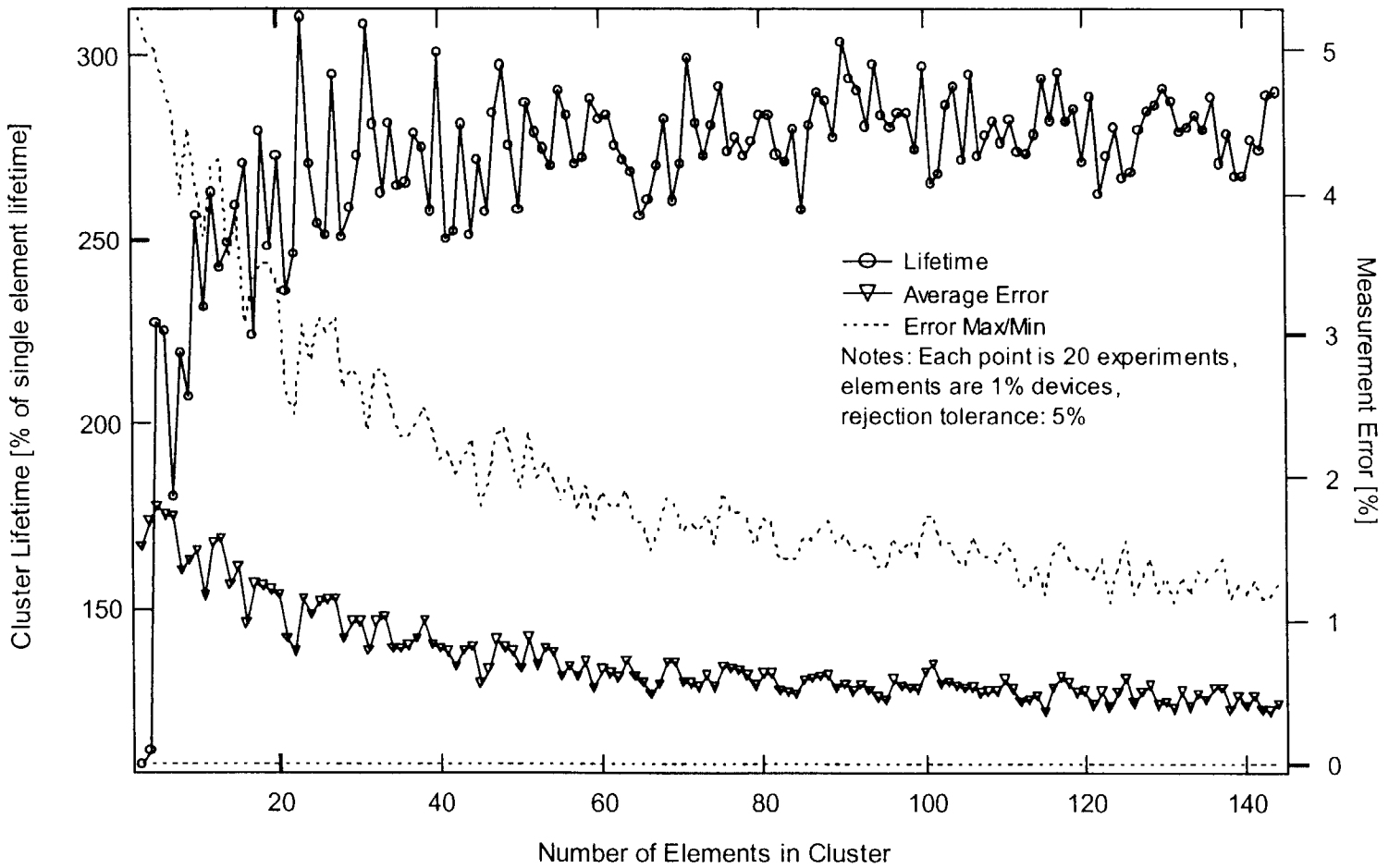
- How do you get sensors to fail in a natural way?
- MSA Algorithm has an analytical proof that algorithm performs correctly (Not to be presented here)
- Monte Carlo Simulation (Theoretical)
- Accelerated Life Testing (Actual Devices)

Monte Carlo Simulation of MSA Algorithm

- Each element is a device with a normally distributed random error of ±1%
- For each element an exponentially distributed random lifetime is generated (with mean 5000)
- After that lifetime has expired, the sensor average and s.d. are changed by ±10%
- Another lifetime is generated for that sensor
- Process repeats
- Experiment ends when there are determined by be less than 3 reliable sensors left
- Each point you see represents 20 experiments

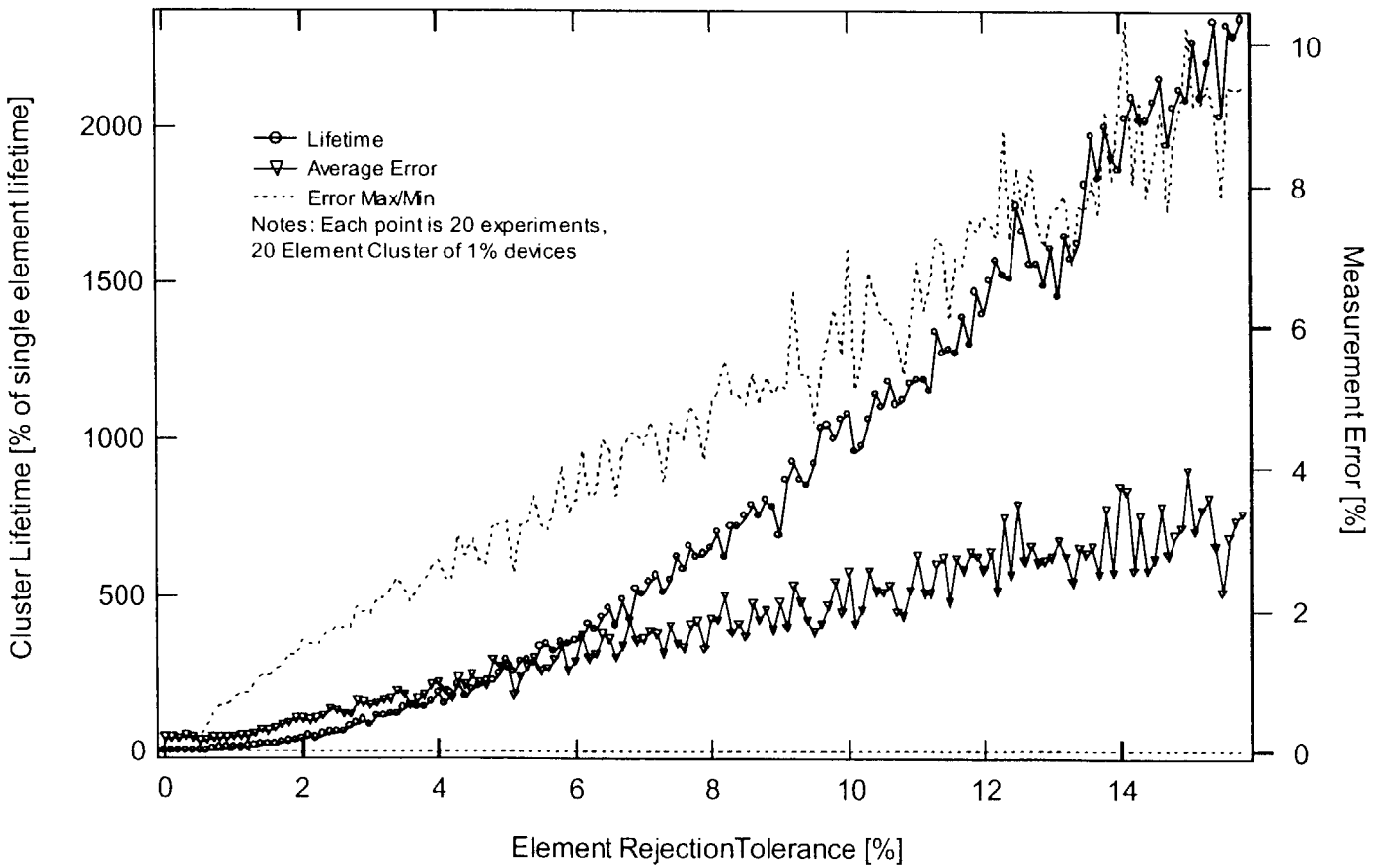
Monte Carlo Simulation

Cluster Lifetime vs. Elements in Cluster



Monte Carlo Simulation

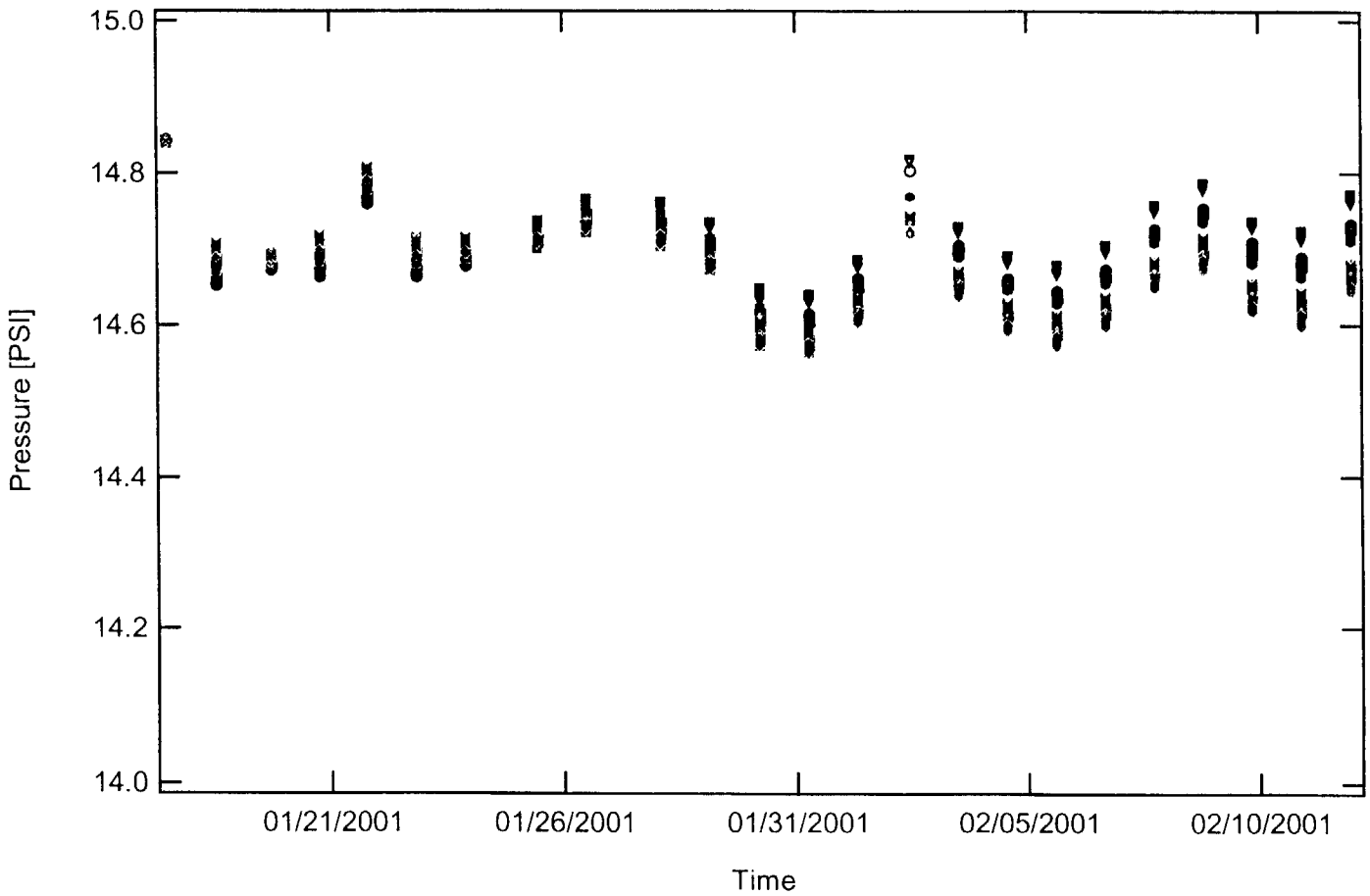
Cluster Lifetime vs. Rejection Criteria



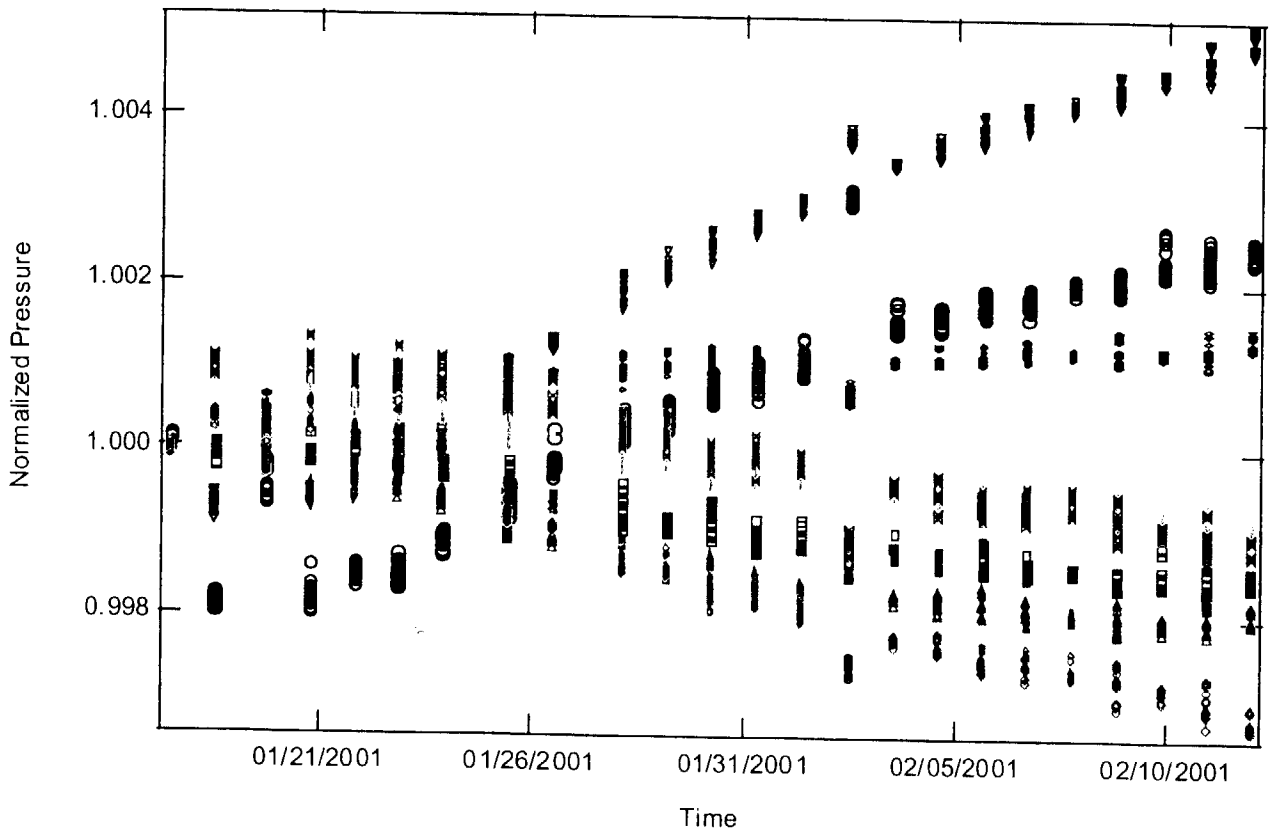
Accelerated Life Testing

- Elevated temperature equates to longer duration time (by some particular function)
- Allows you to increase likelihood of "natural" failure or calibration shift
- Sensors Selected: Lucas Novasensor NPP-301 Series Surface Mount Pressure Sensors, 15 PSIA range
- Procedure: Take 8 sensors, heat them to 125 C and hold, once a day cool to room temperature and take measurements of each sensor, once a week, take calibration measurements vs. standard to check "systematic" errors.

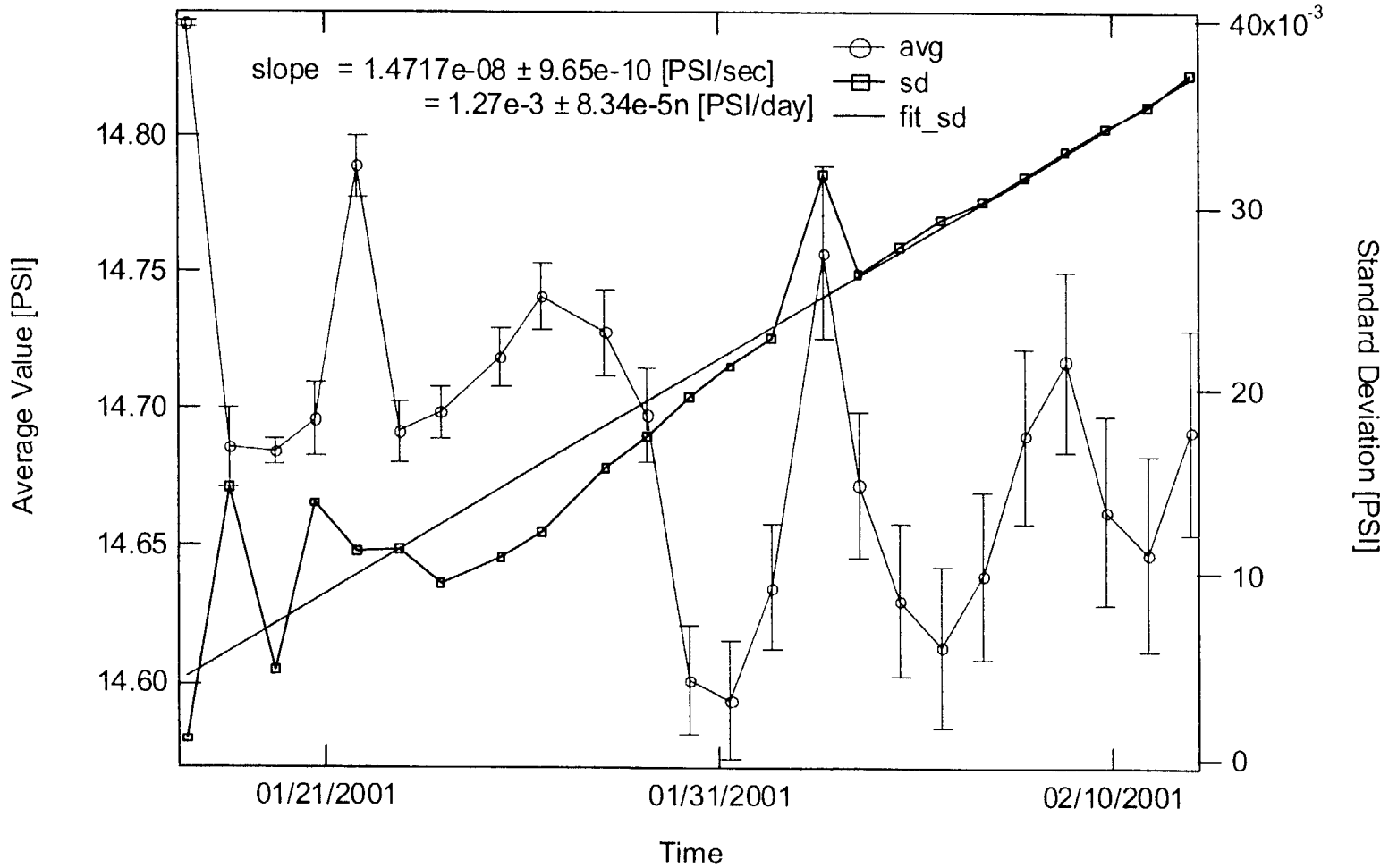
Accelerated Life Testing at 125 C
Raw Data



Accelerated Life Testing at 125C



Accelerated Life Testing at 125C



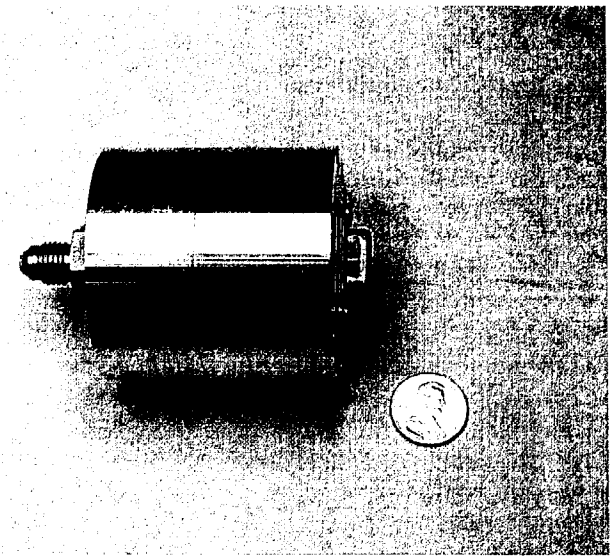
Accelerated Life Testing Results

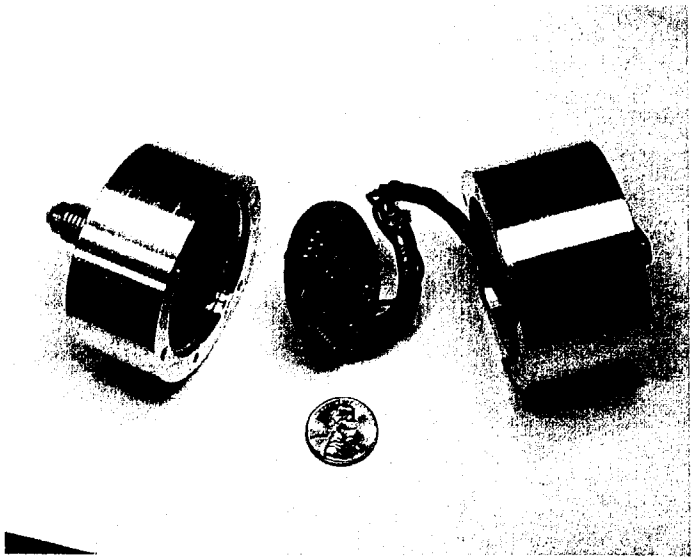
- Sensors have an increasing spread with time
- Sensor cluster average stays approximately the same: no systematic drift
- These sensors behave very similarly to those modeled in the Monte Carlo Simulations
- The Lucas Novasensor pressure sensors have exactly the type of failure modes that work well with the MSA algorithm

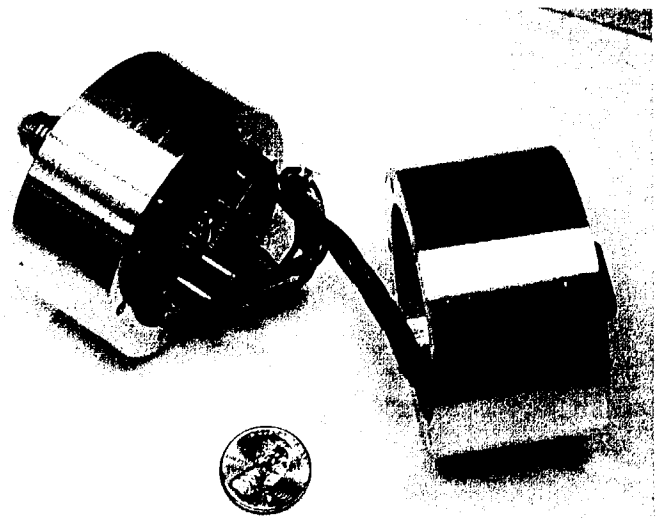
MSA Transducer

- 8 Lucas Novasensor elements
- ADC-Multiplexer
- Microprocessor that does calculations, sends results out serial port, stores calibration to engineering units, keeps history of each element

MSA Transducer Picture(s)







Advantages of MSA Transducer

- With weighting/averaging measurement error will generally be better than individual elements
- Real-time estimate of sensor error delivered with each measurement
- Gives feedback to user when calibration is needed
- Measurement error can be traded for extended lifetime (e.g. during mission to Mars)
- By storing cumulative weights the MSA Transducer **learns** which elements are good and bad: the more that an element misbehaves, the less it is weighted
- Easily applied to any existing sensor(s)

Acknowledgements

- Dr. John Lane
- Anthony Eckhoff, Jose Perotti
- Jeff Reese, Mike Blalock, John Randazzo